# United States Department of the Interior

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IN REPLY REFER TO:
L54(2380)
IMR/SAND

April 22, 2013

**Memorandum**

To: Superintendent, Sand Creek Massacre National Historic Site (SAND)

Through: Dr. Ed Harvey, Chief Water Resources Division (WRD)

Dave Steenson, Chief Geologic Resources Division (GRD)

Gary Rosenlieb, Chief, Aquatic Systems Branch (ASB-WRD)

From: Mike Martin, Hydrologist (WRD), Kevin Noon, Wetlands Specialist (WRD),

Pete Biggam, Soil Scientist, (GRD)

Subject: Technical Report Addressing Historical Channel Position of Big Sandy Creek

Please find attached a **draft** WRD technical report titled "Geomorphic and Hydrologic Assessment of the Historic Channel Position of Big Sandy Creek through Sand Creek Massacre National Historic Site, Colorado." In summary, we found no geologic, hydrologic, or botanical evidence to support the hypotheses that the active channel of Big Sandy Creek was located in a substantially different alignment during the time of the Massacre, 1864, despite several field investigations and comprehensive literature review.

It is our intent to publish this document through our Natural Resource Technical Report series. However, we are providing an advance copy to the Historic Site staff and other NPS personnel for review and distribution to interested parties. Through the publication process, we will be seeking formal peer review, which will include park staff, as well as other professionals in the field.

Prior to finalizing this document, we would expect some changes in the content that might include formatting, organization, figure captions, etc. Additionally, we may choose to add a section or two in order to produce a more comprehensive description of our analyses. While there may be some changes and refinement to the material in the report, we do not expect any deviation from our basic conclusions.

If you have any questions, or would like to discuss any aspect of this document, we encourage you to contact any of the authors via phone or email.

cc: (by e-mail only)
2380 - Smillie, Wagner
SAND – Zimmerman, Campbell,
IMR – Reber, Landrum
IMSF – Bradford, Chattey

National Park Service
U.S. Department of the Interior

Water Resources Division
Fort Collins, Colorado

# *Draft* Geomorphic and Hydrologic Assessment of the Historic Channel Position of Big Sandy Creek through Sand Creek Massacre National Historic Site, Colorado.

## *Evaluation of possible channel shift over the last 150 years*

Natural Resource Technical Report NPS/NRPC/WRD/NRTR—2012/xxx

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Cover Figure Here

**ON THE COVER**
(Big Sandy Creek during a rare storm flow, May 2007)
Photograph by: (NPS, 2007)

# *Draft* Geomorphic and Hydrologic Assessment of the Historic Channel Position of Big Sandy Creek through Sand Creek Massacre National Historic Site, Colorado.

*Evaluation of possible channel shift over the last 150 years*

Natural Resource Technical Report NPS/NRPC/WRD/NRTR—2013/xxx

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April, 2013

U.S. Department of the Interior
National Park Service
Natural Resources Program Center

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## Introduction and Summary

The purpose of this report is to present our conclusions regarding the position of the active channel of Big Sandy Creek at the time of the Massacre, 1864. At the request of the Historic Site (Site) staff, we have evaluated a hypothesis that a substantial reach of the main channel of Big Sandy Creek was actually located in a very different alignment (than its current position) in the mid to late 19th Century. Specifically, the hypothesis supposes that roughly about 5000 to 7000 feet of the main channel and its floodplain (the reach containing the prominent "Dawson's" bend) was located about 1500 to 3000 feet to the north of the existing channel and modern floodplain during the 1864 massacre. While the exact alignment of the hypothetical channel has not been delineated, communication with park staff has placed the hypothetical channel just south and roughly parallel to the 1908 Chivington Canal (canal), (Figure 1).

Several lines of evidence led to the formation of this hypothesis, these include: a variety of historic maps, the results of a cultural artifact survey, and interpretation of first- and second-hand accounts recorded around the time of the Massacre. Alternatively, there are several lines of physical and biological evidence that suggest the modern channel has been within about 100 to 200 yards of its present alignment since the mid 1800's, and probably much longer.

Some of the physical and biological evidence was collected by various researchers in unrelated studies. Results of those studies, which addressed geologic, hydrologic, and botanical characteristics of the immediate area, are presented in several technical reports, all referenced within this document. Additionally, we have conducted several site visits at both the reconnaissance level and more detailed assessments of the surrounding terrain, including on-site investigations of geomorphology and soil analyses in the area of the hypothetical channel. Lastly, the park has acquired detailed light detection and ranging (lidar) imagery of the entire Site allowing us to complete a detailed geospatial analysis of the primary areas in question.

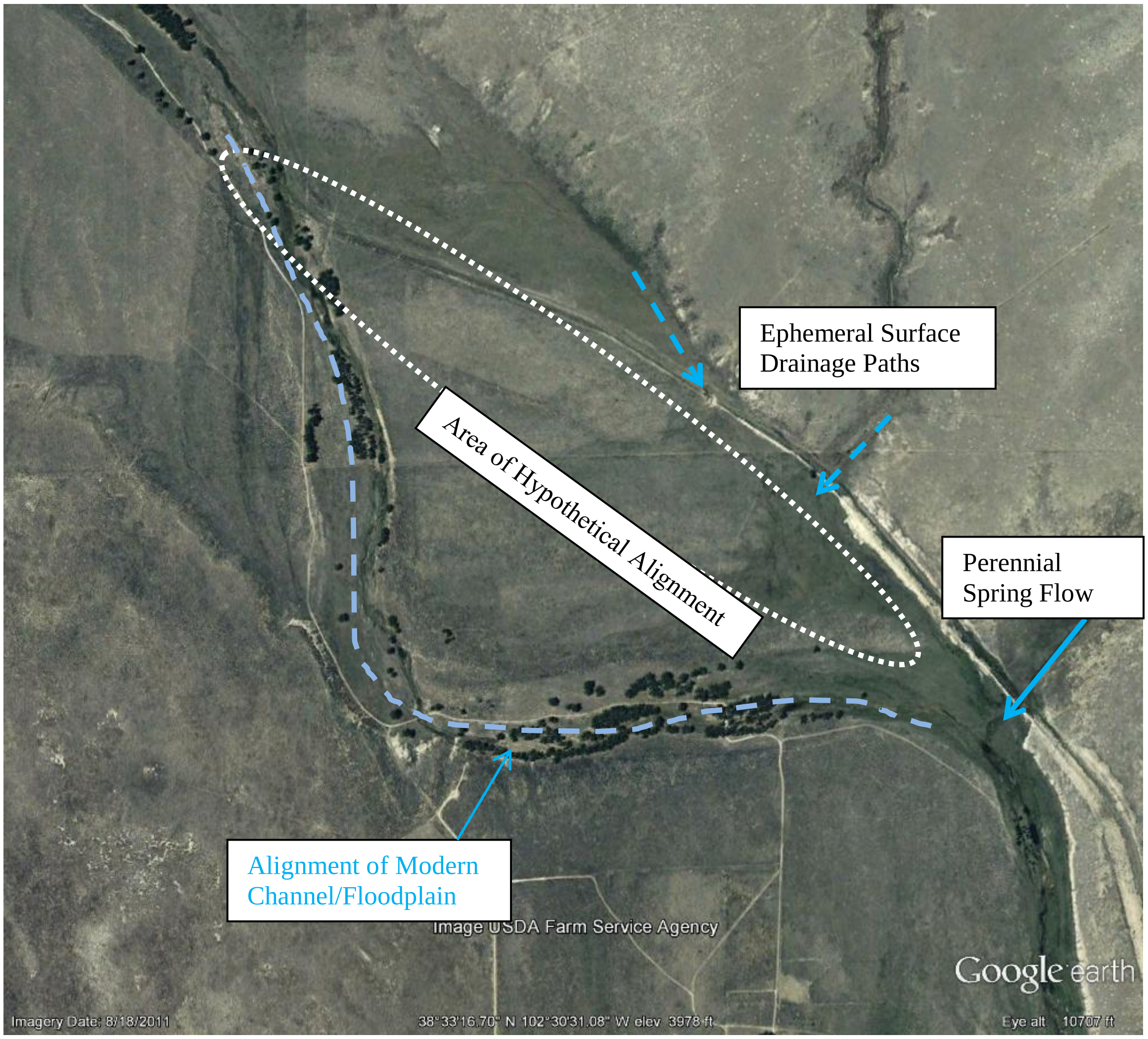


**Figure 1** – Google Earth image of the Big Sandy Creek reach in question. The area of the hypothetical channel is delineated by a dotted ellipse and the alignment of the modern channel and floodplain is depicted with dashed light blue line. Note the influence of surface drainage from the northeast. Blue arrows depict the general ephemeral (dashed) and perennial (solid) flow directions from the adjacent highlands.

To briefly summarize the issue, If the active channel was along the proposed alignment at the time of the Massacre, 1864, then, in the period of about 150 years, the channel and associated floodplain would have had to shifted over 1500 feet to the south and established its present grade, or if it was on the current grade 150 years ago, the abandoned channel and floodplain would have had to have been completely obscured since the shift.

Despite several field investigations, we found no physical evidence that suggests that an active channel existed in the area of hypothetical alignment within the last 150 years. The geomorphic evidence that there was no channel in this area includes: complete lack of channel characteristics, on-site soil investigations and analyses that do not indicate a recently-buried or abandoned channel, the presence of well preserved and extensive river terraces that pre-date the Massacre of 1864, and the complete lack of a favorable topographic gradient along the hypothetical alignment. Consideration of the other physical and biological evidence further supports our observations. This includes: the distribution and age of the cottonwood stands present along the existing floodplain, a number of radiometric dates previously collected from buried soils and pond sediments, and a general infrequency of the kind of surface-water flows required for channel migration and shifting. Consequently, we have concluded that it is extremely unlikely that the active channel was along the proposed alignment at any time in the recent past.

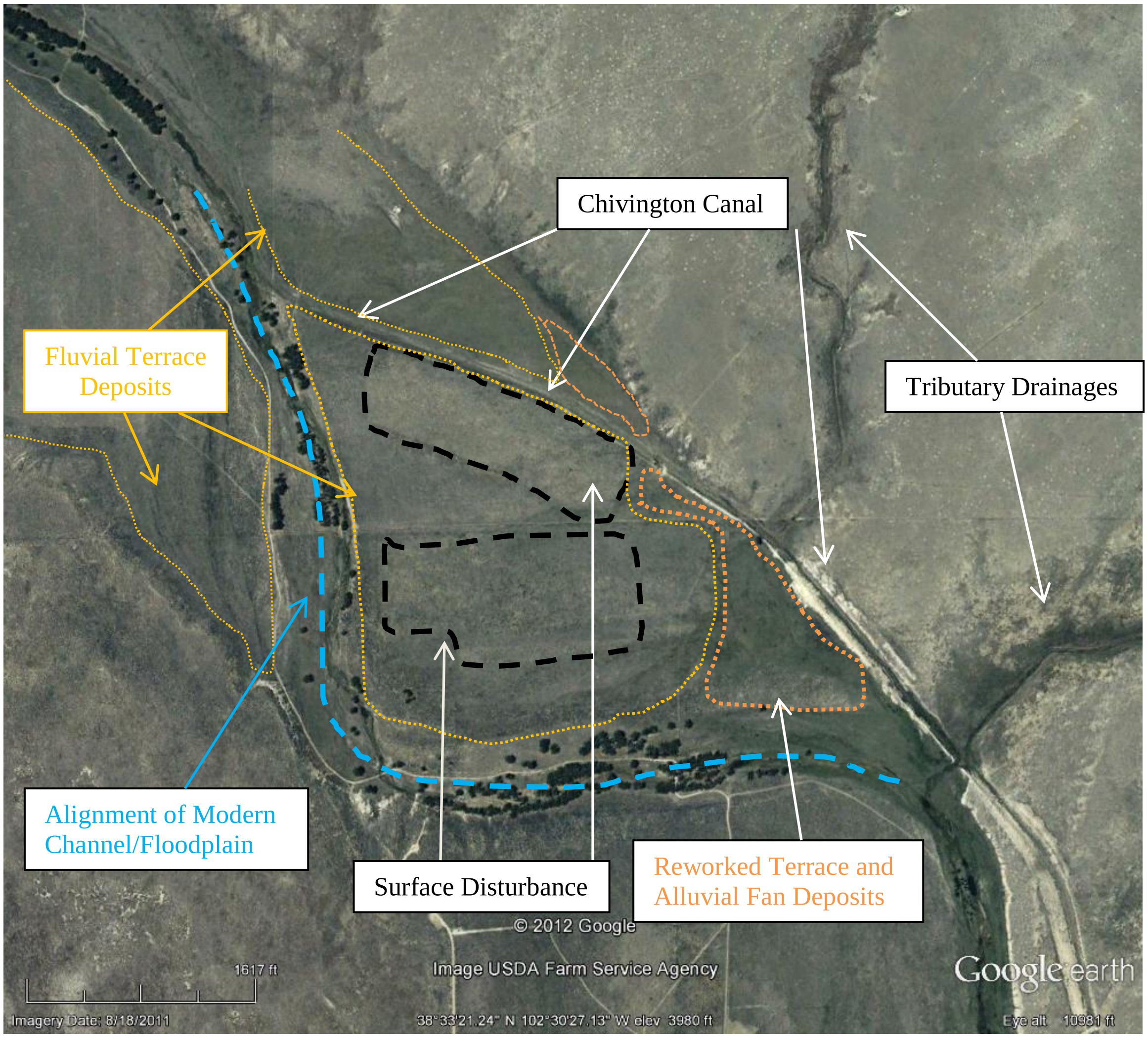


**Figure 2-** Google Earth image of the Big Sandy Creek reach in question showing some of the important physiographic features (dotted lines indicate approximate delineation). Note the relatively large area of continuous fluvial terrace deposits on both sides of the modern channel and canal. Also, note the area of surface disturbance south of the canal, and the two tributary drainages that enter the valley from the northeast. These drainages have influenced hydrologic and sedimentation processes near the lower end of this reach by reworking some of the older terrace deposits.

## Setting/Background

Big Sandy Creek (BSC) is a high-plains stream located in eastern Colorado along the Colorado Piedmont of Great Plains Physiographic Province. The entire Big Sandy Creek drainage basin is about 3,400 square miles, however, according to the U.S. Geological Survey (USGS) only about 2,600 square miles contributes directly to runoff in the downstream reaches. The drainage begins in the vicinity of Limon, Colorado and continues predominantly southeast and south until forming a confluence with the Arkansas River, about eight miles east of Lamar, Colorado. The location of Sand Creek Massacre National Historic Site is along the lower reaches of the creek about 30 miles upstream from the Arkansas River confluence. The Site encompasses about three miles of the creek; the lower half mile supports perennial surface water due to influence from a spring to the northeast (Figure 1). The rest of the stream is intermittent and only flows in response to substantial rainfall events and occasionally from snowmelt.

As the name implies, Big Sandy Creek is an alluvial stream, meaning that its bed and banks are composed of sediment recently transported (in a geologic sense) by the watercourse. The overall configuration of the creek is a meandering alluvial channel under-fit in a broad valley. However, due to the infrequency of flow events, there is little in the way of actual meandering or channel formation at the present time.

The Big Sandy Creek watershed is located in a portion of the country where annual evaporation greatly exceeds annual precipitation. The climate is arid to semi-arid and the entire region has been subjected to periods of prolonged drought. The watershed of BSC does not extend to the high mountains so snowmelt runoff is local and slight at best. Furthermore, most of the watershed soils have high infiltration rates and readily absorb small to moderate runoff events. Consequently surface flows in BSC are rare and usually only driven by intense summer thunderstorms. This rather limited hydrology has had ramifications in the geomorphic evolution of the channel, which in turn, is a fundamental variable that defines the channel position – the location of which is the primary question addressed in this report. Therefore, proper evaluation of recent channel changes must include a fairly detailed understanding of both the geomorphic and hydrologic history of BSC.

## Geomorphic History and River/Floodplain Evolution

To evaluate the recent geomorphic history of Big Sandy Creek through SAND, it is imperative to reconstruct a much greater period of recent geologic history, specifically the later portion of the Pleistocene and early Holocene periods, or about the last 10 thousand years. During this time-frame, the surges and retreats of the mountain-valley glaciers and the associated large quantities of water and sediment from the nearby Front Range were the primary mechanisms that shaped the modern landscape.

The valley that BSC occupies was eroded out of Cretaceous bedrock formations, namely the Pierre Shale, the Niobrara formation, and the Carlile Shale, and subsequently filled with alluvial material as a result of the repeated advance and melting cycles of the Pleistocene glaciers. (Coffin and Horr, 1967). After the period of valley filling, surges in discharge through the late Pleistocene and early Holocene periods reworked the valley fill deposits. Ultimately, episodes of channel incision followed by periods of lateral migration created a series of fluvial terraces at progressively lower elevations, with the oldest terraces at the higher elevations and the younger terraces lower and closer to the modern channel.

The sediments that make up the terraces range in composition from gravel, sand, and silt to clay and were deposited mostly by flowing water (alluvium) but also to a lesser degree by wind (eolian). Volumetrically, the fluvial sediment makes up the vast majority of the valley fill; however, because the eolian deposits are widespread on the surface, they play an important role in understanding the geomorphology. These well sorted, eolian sands may obscure older surface features and boundaries between older landforms, but are generally not deep enough in the valley to hide substantial topographic features such as recently abandoned channels.

The hypothesis under evaluation requires that the active channel of Big Sandy Creek has undergone a dramatic shift in position since the time of the Massacre. In meandering streams like BSC, there are generally two mechanisms for channel shifting; continual lateral migration in response to normal flows, and episodic shifts that often result from extreme flow events. The lateral migration process essentially moves the floodplain across the valley at a near constant grade, eroding through and reworking any older terrace deposits. The episodic shifts, referred to as avulsions, usually occur during more extreme flow events when overbank flows may access an alignment with a more favorable grade and, as a result, establish a new channel. One of the most common examples of this process is abandonment of a meander bend in a stream. Channel avulsions may preserve some older terrace deposits between the old and new channel, but leave behind remnants of the abandoned channels, such as oxbows and meander scrolls.

**Modern Floodplain and Quaternary Terraces**

As mentioned, fluvial terraces have formed along BSC from periods of incision followed by periods of lateral migration of the active channel. Within the greater watershed of BSC, there are at least four fluvial terrace levels in addition to the modern floodplain (Coffin and Horr, 1967). More specific to SAND, a focused study aimed at identifying likely locations of in-situ cultural material within and around the Site identified the presence of three distinct terrace levels (in addition to the modern floodplain level) (Holmes and McFaul, 1999). These researchers designated the modern floodplain and the three progressively older terrace levels as T0 through T3, respectively. As part of this study, the researchers acquired two radiocarbon dates from buried soil profiles in both the T1 and T2 terrace levels, yielding ages of about 1030 and 2390 years old, respectively. These dates indicate that the two terrace levels sampled were in place long before the 1864 Massacre.

In practice, absolute delineation of the different terrace levels in the area of interest is difficult due to variability in the topography from reworking of the sediments in the east and the varying proximity to the active channel, primarily due to the near ninety degree bend of the stream. Nevertheless, we were able to easily distinguish between the modern floodplain and the older terrace deposits (likely the T1 and/or T2 terrace levels) throughout the area based on relative elevation. Consequently, our descriptions in this document will depart from the use of T1, T2 etc., in favor of the more general “modern floodplain,” “low terrace,” and “intermediate terrace” to describe the different fluvial landforms related to this assessment.

The modern floodplain level lies very near the elevation of the active stream channel, and in reaches where there is no defined channel, the channel/floodplain system is essentially a broad greasy swale. The surface of the modern floodplain is relatively smooth with some evidence of recent flows in the form of small channel expressions and flood debris. The width of the modern floodplain is variable but is generally less than about 200 yards. For most of its length through the site, the modern floodplain is bounded by fluvial terraces, mostly the low terrace. On aerial imagery, the modern floodplain and low terrace are easily identified and are basically delineated by the stands of cottonwood trees present today (Figure 1).

As mentioned, the low terrace brackets the modern floodplain through most of its length through the site, but since it is only about one and a half feet (0.5 meters) above the floodplain level, it is sometimes difficult to distinguish. A photo from a storm-flow event that occurred in May 2007 graphically illustrates the difference in elevation between the modern floodplain and the low terrace (Figure 3). The intermediate terrace is much easier to identify as its elevation is about three feet above the floodplain level, somewhat higher in places. One area where this intermediate terrace is especially identifiable is just south of the canal along the left bank of the creek, coincidentally, the same area of the hypothetical channel.

**Figure 3 –** Big Sandy Creek during the storm flow of May 2007. This flow level essentially inundates the modern floodplain but not the low terrace, which is visible on the opposite side of the creek. Photo is taken from near the edge of the low terrace. Note the presence of cottonwoods on the low terrace and the modern floodplain. A portion of the intermediate terrace is visible as a relatively flat horizon in the distant center-right of the photo. NPS, 2007.

### Channel and Modern Floodplain Evolution

An important aspect to understand regarding the geomorphic evolution of BSC is that the current rate of channel formation and migration is very slow relative to streams with greater and more frequent flow events. This is because competent flows, those capable of transporting sediment and re-working the channel, are very rare in BSC. As a result of this infrequency of "channel forming flows," the BSC active channel is poorly defined throughout most of the Historic Site. We know that the modern channel was very near its present grade and alignment in about 1908 because of the position of the canal and its appurtenant features constructed at that time. That leaves only about 45 years between the Massacre and canal construction for the channel shift to have occurred and only about an additional 100 years for the landscape to have achieved its present configuration. The geomorphic features that are generally associated with meandering streams (such as point bars, cutbanks, and overflow channels, to name a few) are largely absent or poorly formed in the modern channel. Herbaceous vegetation has ample time, between flow events, to establish on most of the geomorphic features that may be formed or scoured during flow events. Examination of the systematic flow record available for this stream (detailed in a later section) provides more quantitative insight regarding flow conditions for BSC.

## Geomorphic Soil Assessment

As mentioned, we conducted a detailed on-site investigation of the alluvial soils in the vicinity of the hypothetical channel. This investigation included a total of 10 sites where we used a 3-inch soil auger to extract up to 60 inches of geologic material at each site. We observed and documented all soil properties at these sites using National Cooperative Soil Survey (NCSS) standards.

Since an exact alignment of the hypothetical channel has never been identified, the sampling design was aimed at characterizing intact terrace material, disturbed sites associated with the canal, and a number of other locations within the area of the proposed alignment. Having received input from park staff that the current location of the abandoned canal may have been near the alignment of the hypothetical channel, seven of the sample locations were in the vicinity of the canal. Additionally, we collected one core in the active channel of Big Sandy Creek to document soil properties of the current alignment of the creek (Figure 4). Given the time available, an extensive sampling program was not possible. However, if at a later date, a more specific alignment of the hypothetical channel is identified, a focused sampling program could be conducted in that area.

As a general description, the soil types within the area of interest are one of two groups; the Bankard-Glenberg complex, which occur in the area of the alluvial terraces, and the Fluvaquents, which are in the area of the modern floodplain, but also occur along the alignment of the canal and in the area that has been reworked by the drainages from the northeast. Both of these series consist of deep, terrace and floodplain soils with very gentle slopes, typically 0 to 1 percent. The Bankard-Glenberg complex is generally well drained and formed on sandy alluvium while the Fluviquants are poorly drained and formed on mixed alluvium, (SCS, 1977).

Specific to the area of interest, the landscapes and soils of Sand Creek Massacre National Historic Site have been significantly impacted by accelerated wind erosion and deposition, as an ongoing process, and especially as part of the Dust Bowl in the 1930's. Additionally, impacts to the soil resources have occurred since Anglo occupation thru a variety of agricultural practices such as mechanical cultivation, rangeland seeding, and livestock grazing. The canal has also affected the soils in the site, due to surficial impacts of land scarification and excavation during its construction, and its use may have altered subsurface soil properties such as indicators of soil drainage due to leakage of the canal. Also, the canal alignment currently provides a conduit in which runoff is collected and redirected to the eastern and southern portions of the area of interest, thus reworking soils in this area (Figures 1 and 2). Since the park was established, these agricultural practices have been discontinued throughout the site, however, these anthropogenic impacts have had lasting effects on the soil properties. From a soils perspective, these impacts are mainly confined to the upper 8 to 20 inches of the soil surface, with the subsurface soil horizons and physical soil properties remaining fairly intact, other than from potential impacts from the altered hydrology associated with the canal.

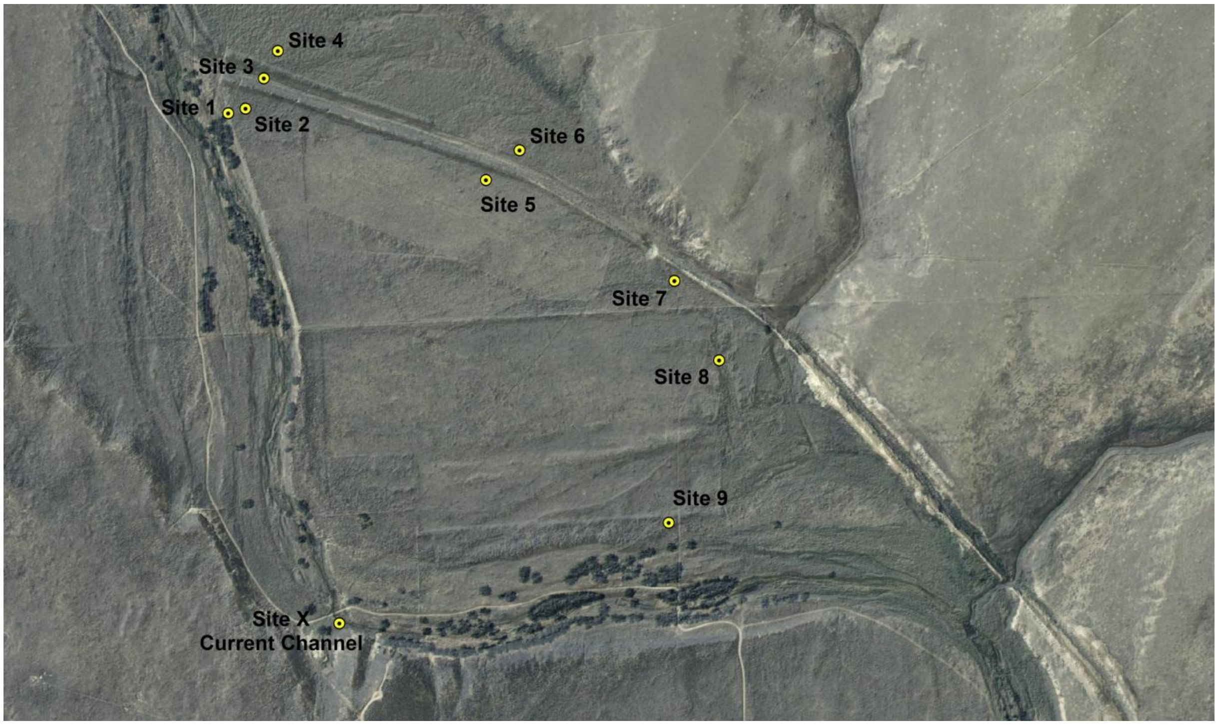


**Figure 4**. Location of the 10 Soil Geomorphic Assessments (2011 National Aerial Imagery Project Image over a sub- meter hillshade lidar model). Note the degree that surface disturbances show up on the hillshade image, specifically the scarified area just south of the canal, and the agricultural area farther to the south. A Fenceline is visible as a continuous, east-west lineation through the center of the image, NPS 2011).

Following the conditions of basic soil morphology and genesis that would be present in this area, a soil with an absence of secondary calcium carbonate accumulation below the initial soil surface, subsurface soil horizons of stratified sand and gravel, and the indication of a shallow water table such as mottled or reduced soil colors, would suggest that that soil is very young, the kind you might find in a recently abandoned channel.

This presumption is supported by the core sample we collected at site "X" in the active channel of Big Sandy Creek, which displayed all three of these conditions.

The following table (Table 1) provides an overview of each soil geomorphic assessment site, the landform where it was collected, the observed soil series or soil taxa documented, and comments regarding critical soil properties such as soil texture, soil drainage, accumulation of secondary calcium carbonate, and presence or absence of a water table encountered within the upper 60 inches of the soil.

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**Table 1. Overview of Soil Geomorphic Assessments**

| Site | Landform | Soil Type | Comments on Observed Soil Properties |
|---|---|---|---|
| Site "X" | Active channel/low terrace | Typic Fluvaquents | Site was chosen to characterize a soil type that was forming in or adjacent to an active stream channel of Big Sandy Creek. Upper 8 inches of soil is a fine sandy loam, with stratified sand, gravelly sand, and very gravelly coarse sand encountered at 8 inches to a depth greater than 56 inches. Soil moist at 11 inches, and soil saturated at a depth of 14 inches to a depth greater than 56 inches. Secondary accumulation of calcium carbonate not detected in soil. |
| Site 1 | Low/Medium Terrace Interface | Bankard series | Very deep, well drained soil forming in eolian material over stratified alluvium. Depth to secondary accumulation of calcium carbonate accumulation 7 inches, and increases with depth to 60 inches. Soil was dry throughout. |
| Site 2 | Medium Terrace (possible alignment of hypothetical channel) | Bankard series | Very deep, well drained soil forming in eolian material over stratified alluvium. Depth to secondary accumulation of calcium carbonate accumulation 11 inches, and increases with depth to 60 inches. Soil was dry throughout. |
| Site 3 | Abandoned Canal Bottom | Typic Fluvaquent, altered | Soil was disturbed, and current soil surface texture is a clay loam, potentially due to addition of finer soil materials from canal sediments, or if a clay liner may have been used. Secondary accumulation of calcium carbonate detected in a small discontinuous layer below soil surface (4 – 13 inches depth). Mottled coarse sand encountered at 14 inches, and a zone of saturated gravelly sand found from 34 – 54 inch depth. Evidence of water table from 14 inches to greater than 54 inches. |
| Site 4 | Medium Terrace | Glenberg series | Very deep, well drained soil forming in eolian material over stratified alluvium. Depth to secondary accumulation of calcium carbonate accumulation 8 inches, and increases with depth to greater than 55 inches. Soil was dry throughout. |
| Site 5 | Medium Terrace w/ Surface Disturbance | Typic Fluvaquent, altered | Site located within area where the original 3 to 15 inches of the soil surface was removed, most likely as borrow material for the adjacent canal located directly to the north. Depth to secondary accumulation of calcium carbonate 7 to 23 inches. Stratified gravelly loamy sand at 23 to 35 inches, |

| | | | |
|---|---|---|---|
| | | | with evidence of soil saturation at 35 to greater than 57 inches. |
| Site 6 | Medium Terrace | Glenberg series | Very deep, well drained soil forming in eolian material over stratified alluvium. Depth to accumulation of secondary calcium carbonate 9 inches, and increases with depth to greater than 59 inches. Stratified gravelly loamy sand at 51 inches to a depth greater than 59 inches. Soil was dry throughout. |
| Site 7 | Medium Terrace (may have been altered, located southeast of breach in canal, evidence of previous livestock use) | Typic Fluvaquent, altered | Site located approximately 200 feet southeast of breach of canal, in what appears to be on the border of a T1/T2 landform boundary. The T1 landform is associated with drainage occurring to the east. Depth to secondary accumulation of calcium carbonate 5 to 33 inches. Stratified loamy sand and gravelly sand at 33 to greater than 59 inches, with evidence of soil mottles and soil saturation at 51 to greater than 59 inches. |
| Site 8 | Medium Terrace (terrace is related to drainage occurring to the northeast of the site off bluffs) | Typic Fluvaquent, heavy clay, saline substratum phase. | Site occurring in a shallow depressional area receiving runoff and sediment from drainage located to the northeast in which soil parent materials are saline shales. This site has a different geomorphological history than the other sites in which we can see that the soils are not as influenced with eolian sands as other sites. Salts occurring at 15 inches, and heavy clay accumulation at 27 inches, with evidence of mottles at 36 inches. Soil was saturated at 36 inches to greater than 57 inches. |
| Site 9 | Medium Terrace | Glenberg series | Very deep, well drained soil forming in eolian material over stratified alluvium. Depth to accumulation of secondary calcium carbonate 9 inches, and increases with depth to greater than 59 inches. Stratified gravelly loamy sand at 51 inches to a depth greater than 59 inches. Soil dry throughout. |

There was no indication in any of the sampling sites (with the exception of Site X) of the presence of a recently buried channel. The presence of calcium carbonate at some depth within all cores (except the one from the modern channel) indicates long-term, in-situ processes. Furthermore, while many of the cores displayed signs of surface disturbance, these indicators were restricted to the upper surface layer. Given the relatively slow soil forming processes in this climate, it is unlikely that any substantial feature buried within the last 150 years would have developed indications of soil formation in that short of a timespan.

## Hydrology of the Big Sandy Creek

The hydrologic regime of this watershed, or more specifically, the magnitude, frequency, and duration of flows, provides context for the geomorphic dynamics associated with BSC, especially as they relate to channel formation and evolution. As mentioned, "channel forming flows" are those most responsible for evolution of alluvial channels. These are the bankfull or near bankfull flows that generally occur every year or so in an average stream system.  Review of anecdotal reports regarding flow in BSC as well as the streamflow records available from a downstream gage, indicates that substantial flows in this drainage are fairly rare.

The USGS gage (#07134100) located above the confluence of BSC and the Arkansas River, began operation in 1968 and has continued to the present time with a number of missing years from 1983 -1995.  The annual peak flows recorded in this time period range from about 100 to 500 cubic feet per second (CFS), with an occasional peak around 500-600 CFS (Figure 4).  For comparison, regional flood frequency equations developed for Eastern Colorado and adjacent portions of Kansas, Nebraska, Texas, and New Mexico, suggest that an “average” watershed of this size should have an annual peak flow in the range of about 1790 cfs (Ries and Crouse, 2002).  Consequently, BSC appears to be much less active hydrologically than other streams in this region.  Only twice in the 31-year record did peak flow at this gage exceed the modest discharge value of 700 cfs, once in 1976, and again in1999 (Figure 4).  These two peak flows were 2,520 to 2850 cfs, respectively.  While these values are markedly higher than an average annual peak flow for this gage, they are still well below the regional estimate for a 5-year event.   So, in 31 years of record, this gage has only measured two flows greater than the estimated 2-year regional event and nothing approaching a rarer flood such as a 50- or 100-year event.  Based on regional estimates, this watershed appears to be very inactive with respect to common as well as rare, high-flow events.

While comparison to regional estimates is instructive, it generally does not describe precise, site specific flood conditions due to unique and local watershed characteristics.  When a reasonably long, systematic gage record of annual peak flows exists for a particular drainage, flood frequency analyses from that gage record usually provides the best description of the local flood regime.  In the late 1990’s, the Colorado Water Conservation Board calculated a 100-year flood value from the gage record that existed for BSC at that time. The relatively short record of 23 years produced an estimate for the 100-year flood of 2,577 cfs (CWCB, 1998).   Adopting this value as a reasonably credible estimate of the 100-year flood magnitude, then BSC has experienced two relatively rare events in the last 30 or so years (1976 and 1999) yet there has been no obvious channel shift or marked geomorphic evolution as a result.

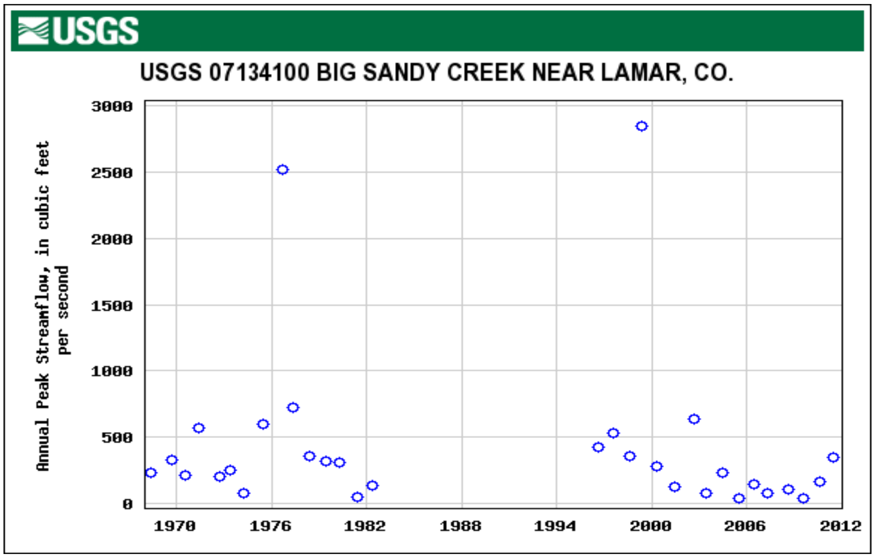


**Figure 5** – Graphical representation of measured peak flows at the USGS gage located just upstream from the confluence with the Arkansas River near Lamar. USGS, 2012.

Another way to assess flow distribution is to evaluate the mean daily discharge in terms of probability of exceedance. Figure 5 is a flow duration curve that shows percent of time during which specified discharges were equaled or exceeded at the gage on BSC during the period of record. This figure demonstrates that most of the mean daily flow values are between about one and 10 cfs. More specifically, the relatively low value of 10 cfs is only equaled or exceeded at this gage about 25–30 percent of the time, and more substantial flows like 100 cfs occur less than three percent of the time.

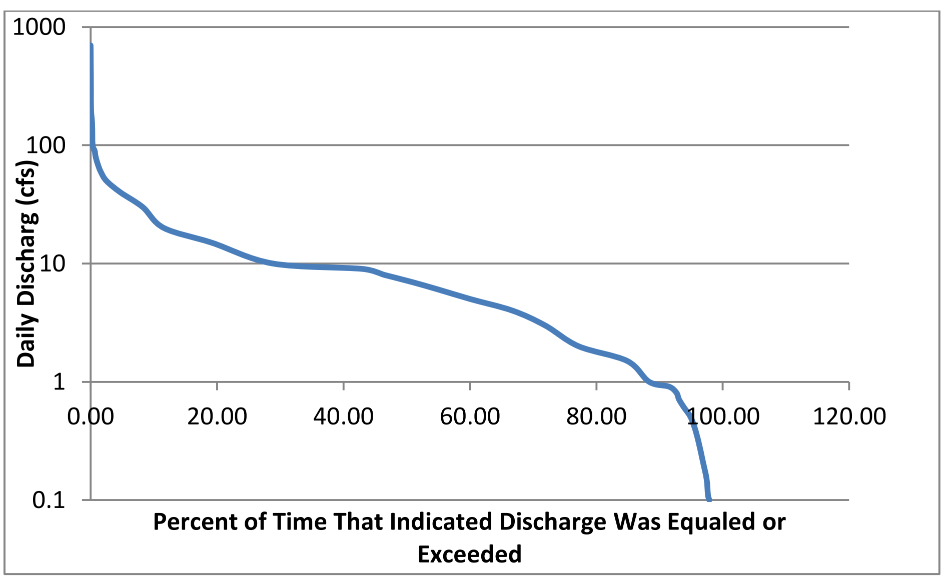


**Figure 6** – Flow duration curve of mean daily flows from the gage record on BSC. Note that mean daily flows only exceed 10 cfs about 25-30 percent of the time and rarely exceed 100 cfs. Furthermore, very low flows (below 1 cfs) occur about 10 percent of the time. WRD, 2012.

These relatively low flow values are generated from a contributing area that exceeds 2000 square miles, further suggesting that this watershed is relatively “inactive.” Large flow events do occur, but they are very rare and short lived. More importantly, regular channel forming flows, those most responsible for channel migration, are also very rare. Consequently, the systematic gage record available for BSC supports the supposition that geomorphic evolution resulting from streamflow is extremely slow in this drainage.

## The Proposed Alignment of the Hypothetical Channel.

As mentioned, the exact alignment of the hypothetical channel has never been delineated, but rather relegated to a general area mostly south and roughly parallel to the alignment of the canal. This would place the hypothetical, 1864 channel from about 1500 to 3000 feet north of the modern day channel and floodplain, for a substantial length of at least 5000 to 7000 feet (Figure 1). Given the meandering nature of this type of creek and the fact that the proposed channel alignment is within the stream valley, it is not unreasonable to hypothesize that the channel could have been at the suggested location at some time in the distant past. The question is: could the channel have been there in 1864 and moved to its present alignment within this relatively short (geologically) time-frame?

As mentioned, there are two general mechanisms by which meandering streams adjust their channel position: 1) slow migration across the floodplain, and 2) rapid re-alignment (avulsion) to a very different position within the valley. Both of these processes leave behind identifiable channel and floodplain features. Looking at the current configuration of the stream system, it appears unlikely that slow migration from the hypothetical position could have taken place. This process of stream meandering tends to destroy any older terrace deposits in the meander path, and since the intervening area is characterized by well-preserved fluvial terraces, slow migration across the floodplain appears to have not taken place. A possible explanation could be that the entire fluvial system was on-grade with the medium terrace (about three feet above the modern channel and floodplain) and the river meandered southwards over the terrace surface and then downcut to its present elevation. Not only is it very unlikely that this amount of geomorphic work with the removal of vast quantities of sediemnt could have been accomplished by this stream system in the relatively short 150 year time frame, but pond sediments in the downstream reach indicate that the stream was at its present grade in the mid-1850’s (detailed in a following section). Consequently, it appears that channel avulsion is the only mechanism by which the hypothetical, 1864 channel could have shifted to its current position.

By their nature, channel avulsions are generally rapid and tend to occur during flood conditions, usually by “capturing” a more favorable gradient or alignment. This rapid shift leaves behind some abandoned channel and floodplain features identifiable on the landscape. Consequently, had the hypothetical channel avulsed to the existing channel, there should still be some evidence of the former channel and floodplain along the proposed alignment.

#### Lack of Channel Characteristics in the Hypothetical Area

The area of the hypothetical alignment, as well as most of the surrounding area, is characterized by relatively high elevation fluvial terraces on both sides of the active channel and the canal (Figure 2). Despite careful examination, we were unable to locate any geomorphic features suggestive of former channels associated with BSC in the area of the proposed alignment (Figures 7). A topographic cross section (A-A') developed from the lidar derived digital elevation model gives no indication of remnant channel features anywhere along the terrace surface, including the area of the proposed alignment (Figure 8). However, there has been some obvious surface disturbance immediately south of the canal and also farther south on the terrace surface, and, there are obvious impacts from the canal construction itself.

Examination of the canal features suggests that it was mostly a cut-and-fill operation with excavated material sidecast to form the banks of the canal. There is no reason to suppose that the canal was located over an abandoned channel, which likely would have required some filling to match grade with the rest of the structure. Even if the abandoned channel was near the design grade, at some point the canal would have had to deviate from the channel alignment in favor of the canal alignment and there is no indication of this on the landscape.

The hillshade image produced from the lidar data is particularly useful in distinguishing features on the surface as it simulates a low sun angle striking the bare-earth topography (Figure 7). The disturbed area south of, and adjacent to, the canal appears to be a borrow area where the surface soil was scraped and pushed north to augment the southern bank of the canal. Farther to the south there is another surface disturbance, which was reported by the former landowner to be an area where cultivation farming was attempted, however, this activity was not very successful (Pers Comm. Dawson, 2012). Therefore, the farming was not long-term and did result in major land alteration. Overall, it is not likely that any of the surface disturbances (grading for the canal or plowing) extended below the natural grade of the terrace deposits for more than a foot or two. This conclusion is further supported by the several soil samples collected in this area, which all had intact soil and fluvial features at greater than two feet of depth.

In addition to anthropogenic surface disturbance, eolian deposition could obscure fluvial features to some degree. However, this type of deposition is extremely variable in thickness over relatively short distances within this valley, and has unlikely achieved coverage or depths great enough to completely mask the features of an abandoned channel and floodplain. This supposition is well evidenced by the easily identifiable location of canal features even though the canal has been in place for about 90+ years and existed through two recorded "dust–bowl" events.

It is important to note that there are some identifiable channel features on the terrace surface in the extreme east and southeast area of the proposed alignment. However, due to the width, orientation, and location of these features, we attribute them to the drainages that enter the valley from the northeast (Figure 7).

To summarize, there are no discernible channel and floodplain features suggestive of BSC in the area of the hypothetical alignment. Most of this area is characterized by well preserved fluvial terraces that are about three feet or more above the modern channel and floodplain. Areas where the terrace deposits are not well preserved have obviously been reworked to some degree by surface drainage from the north and northeast.

Anthropogenic disturbance is obvious through much of the area, however, this did not likely extend below the terrace surface by more than a foot or two. Eolian deposits exist throughout the area but are not deep, nor extensive enough to completely obscure any remnant channel features. So, not only were we unable to identify any channel or floodplain features leftover from an abandoned stream alignment, but we could not identify any processes, natural or human-caused that could likely obliterate or obscure such features.

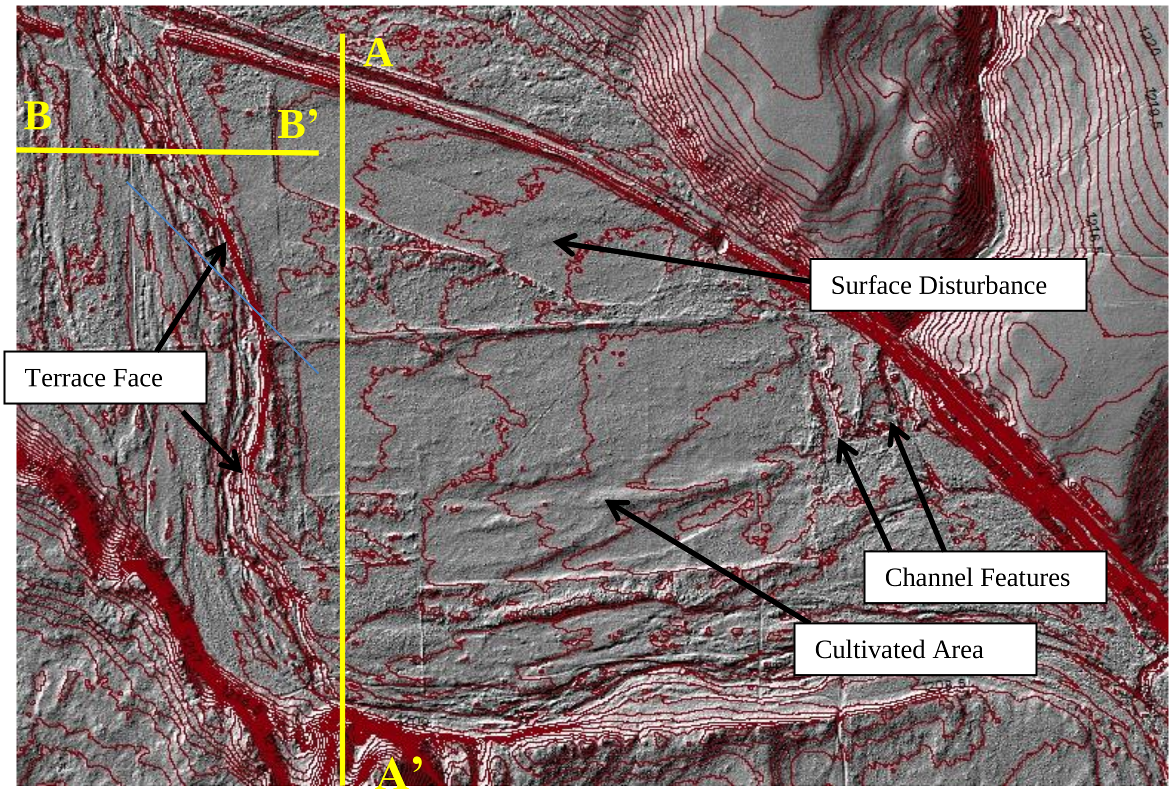


**Figure 7** – Lidar generated, hillshade image of the area in question with 0.5 meter contours (red lines) superimposed on the surface. Note the prominent terrace face on the east side of the modern channel and floodplain. This three to five foot scarp extends from the headgate area almost to the prominent bend in the south with no visible breaks or gaps. Additionally, there is no obvious expression of channel features on the terrace surface in the area of the proposed alignment, even though minor topographic features such as surface scrapings and fencelines are well displayed. (NPS, 2012).

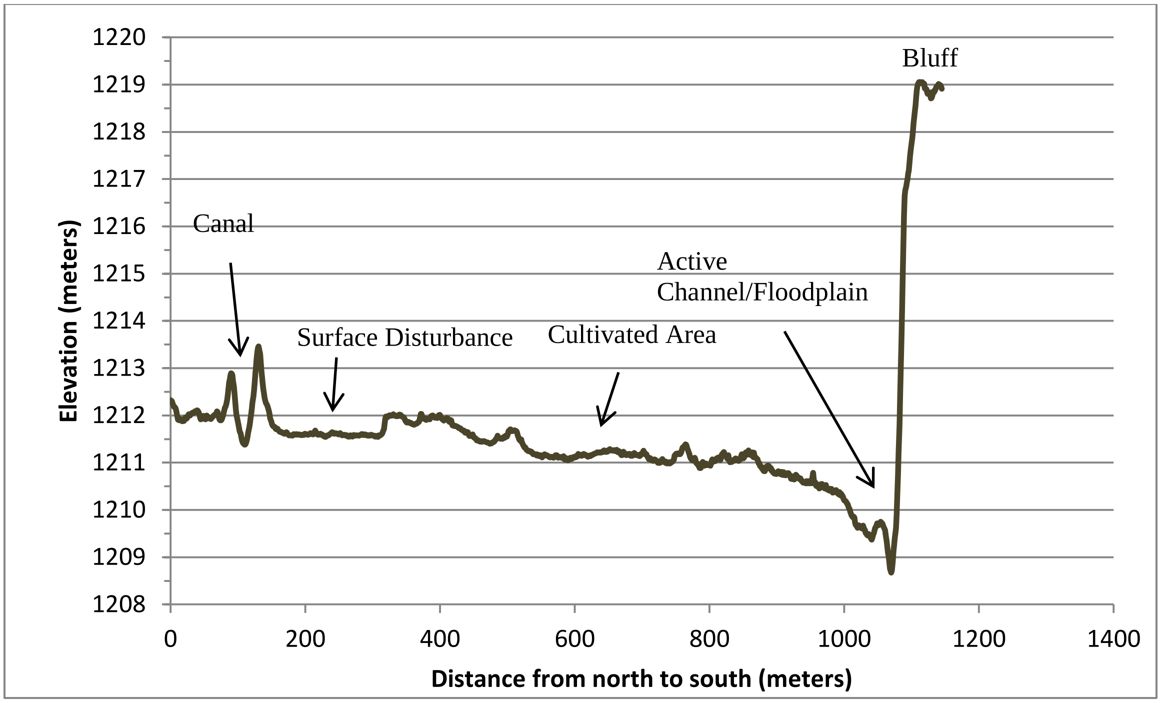


**Figure 8** – Topographic cross section plot A-A' from north of the canal to the southern bluff. Note the difference in elevation between the active channel/floodplain and most of the terrace surface, 1.5 to two meters or more.

**Gradient and Elevation Discrepancies**

Related to the lack of channel characteristics in the hypothetical alignment, the presence of extensive terrace deposits elevated well above the modern channel and floodplain indicate that there has been no active channel here for a very long time. As a further illustration, these terrace deposits represent an adverse gradient for any potential flowpaths from the current channel through the hypothetical alignment. In order to convey flow, a hypothetical channel would have had to match grade with the modern channel and floodplain by connecting both upstream and downstream reaches. Currently, any connection in gradient is blocked by an abrupt terrace face that borders the eastern bank of the active channel. A soil sample collected at the terrace face (Sample 1) indicates this is an in-tack fluvial deposit with a thin eolian cover, and secondary carbonate at a depth of about 7 to 60 inches. This face or scarp is near the angle of repose and ultimately reaches a height about three to five feet above the active channel (Figure 9). This scarp is very continuous with no evidence of a gap or breach all along the eastern bank of the creek between the area of the canal headgate, almost to the prominent bend to the south, well illustrated by topographic plots of the active channel and the crest of the terrace face (Figure 10).

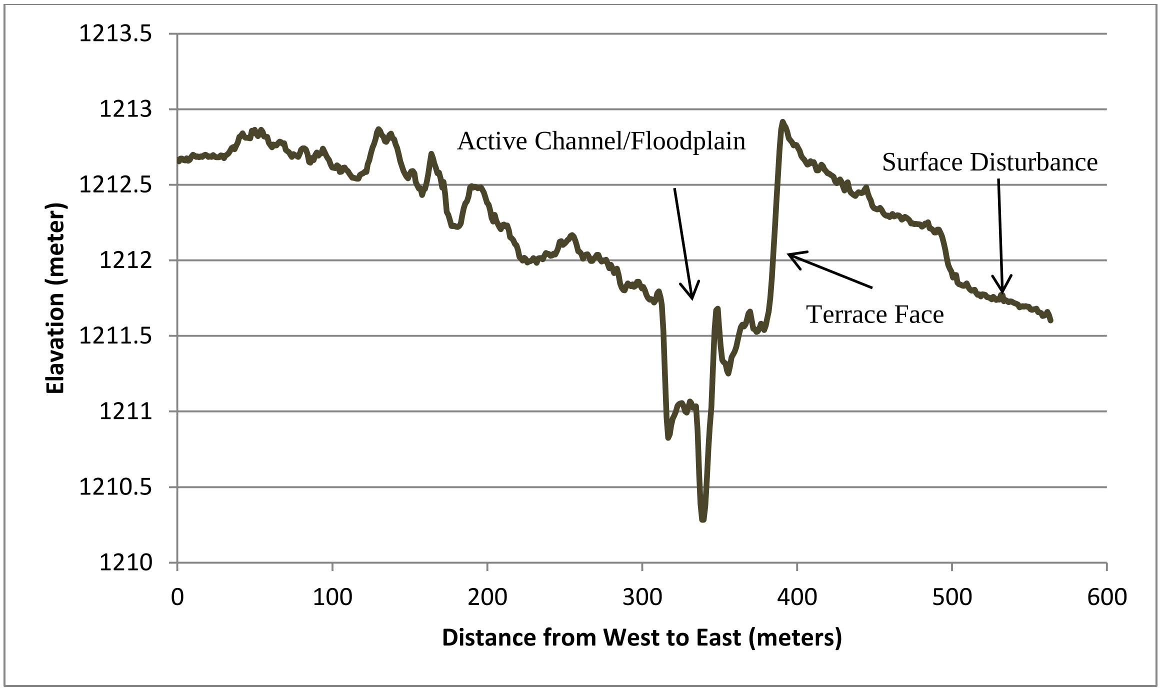


**Figure 9** – Topographic cross section plot B-B' from the western terrace through the active channel/floodplain and the terrace face east of the channel, ending in the area of surface disturbance. Note the abrupt terrace face that borders the eastern side of the active channel. This face is continuous through this reach of the stream from the canal inlet south to the prominent bend. While this face does vary in height, there are no obvious breaches or gaps.

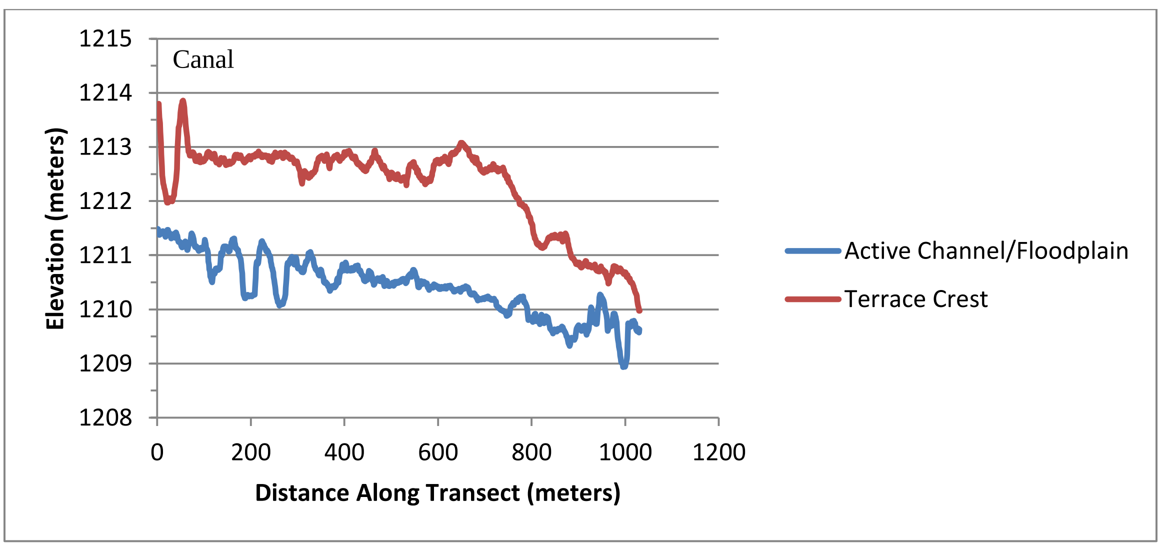


**Figure 10** - Comparison of active channel/floodplain elevations to the terrace crest immediately east. These transects begin in the north near the canal (note canal cross section at far left) and end in the south where the channel bends to the east. Distances and elevations were derived from the lidar generated digital elevation model.

**The Distribution and Age of the Cottonwood Stands**

One of the best proxy indicators for assessing recent positions of an active channel is the location of flood-dependent, riparian, cottonwood trees. Well established cottonwood galleries exist sporadically throughout the length of BSC within the Site. All of the individual trees are mature and appear to be in overall good health although numerous individuals are approaching the end of their lifespan. In 2005, Lukas and Woodhouse from the Institute of Arctic and Alpine Research in Boulder, Colorado conducted a detailed sampling of the cottonwood galleries within the floodplain valley. In brief, the researchers identified three age classes along the BSC drainage. The oldest class had an estimated germination date range of 1865 – 1885 (period trees). The two other age cases identified were 1908 – 1925 (century trees) and 1949-1960 (recent trees, please see Figure 5). There has been little to no cottonwood establishment since 1960.

In floodplains where cottonwoods are the dominant woody plant species, the formation of cottonwood galleries is a unique and predictable process. The cottonwood seeds require saturated soils as a germination medium during a critical time window (approximately three weeks) during which the seeds are viable or capable of germinating once they are windblown or rain washed from the tree. The soil surface on which the seeds land must also be free of other plants that would compete with the seeds for soil moisture. Cottonwood seeds in the BSC drainage mature and disperse in the spring. If surface flows occur at the same time as the when the viable seeds disperse, the seeds tend to be pushed by wind or currents to the outer edges of the surface water body. As a result, one often finds the cottonwood galleries clumped together in one age class or arranged in a crescent-shaped gallery that reflects the outer edge of the floodwaters at the time of seed germination. One other variable that affects the success of cottonwood establishment is the presence of soil moisture, at the soil surface, that exists long enough to allow the seedlings to root and allow the roots to grow down into the soil while following the drop of the ground water as it descends below the soil surface. While this is the typical series of conditions necessary for gallery formation, cottonwoods do germinate in ravines and other wet drainage areas as individual trees.

Based on review of historical meteorological and hydrologic data, the cottonwood establishment dates of the three age classes appear to roughly coincide with recorded flood or high-flow events in the area. This follows the accepted model of cottonwood recruitment being associated with substantial floods and spatially tied to the channel and floodplain system as described above. Additional results from the study suggest that during 1865-1885, the climate in the study area was on average somewhat drier than normal. Drought conditions prevailed from 1859-1865, and returned in the mid-1870s, followed by an extreme drought year in 1880, further supporting the conclusion that substantial flow events through recent times are rare in this drainage, (Lukas and Woodhouse, 2006).

All of the cottonwood trees within the Site, with the exception of a very few individuals, are located within about 500 feet of the existing active channel, and the majority of those are within about 200 feet of the channel. Individuals from the most recent age class, 1949 – 1960, are very close to the active channel. The two older classes, 1865 – 1885 and 1908 – 1925 are also located mostly along the alignment of the modern channel and floodplain but somewhat farther from the active channel (Figure 11). Practically all of the cottonwoods present are on either the active floodplain or the low terrace. Being closest to the existing active channel, the trees in the most recent age classes likely germinated during spring high-flow events where the active channel was at or near its current location. Being further from the existing channel, the older age classes may have germinated during spring high-flow events when the active channel was located closer to those galleries. The arrangement of different age-class galleries within 500 feet of the existing channel, and consideration of the typical conditions necessary for seedling establishment, strongly suggests that the active channel of BSC may have undergone some relatively minor lateral migration since 1865, but the present channel alignment has been basically the same for the last 150 years or so.

**Radiometric Dates from Buried Soils and Pond Sediments**

Two different types of radiometric dates have been acquired from sediment in the vicinity of Big Sandy Creek. Carbon-14 was used to date two buried soil profiles encountered in two different terrace levels in the vicinity of the canal, and Lead 210 dates have been established for sediments collected from one of the ponds in the downstream reach of the creek.

The two radiocarbon dates that were collected as part of the study completed by Holmes and McFaul and were collected from buried soil horizons within two different terrace levels, reportedly T1 and T2. Unfortunately, the exact location of these samples is unrecoverable, but they were reported to have been collected in the vicinity of the canal, which would also place them in the vicinity of the hypothetical alignment (Figure 11). The reported date of the organic material collected at a depth of 23cm in terrace level 1 (T1) was 1030+/- 70 yr. before present (BP), and that reported from a depth of 97cm from terrace level 2 (T2) was 2390 +/- 110 yr. BP. Even though the exact location and the specific terrace levels of these samples cannot be confirmed, these results indicate that the terrace deposits in the area of the canal were in place long before the time of the Massacre. This is a significant finding because any location where an intact terrace of such age exists is also a location where the active channel of the river could not have been in 1864.

The lead 210 dating of the pond sediment (located in the modern floodplain) shows a continuous accumulation in the pond from the present time (near the surface of the sediment) back to about 1850 (found at a depth of about one foot). Deeper sediment was retrieved but this particular type of radiometric dating will only reach back to about 1850, with no associated error reported with these analyses. Nevertheless, these results indicate that that pond has been in its present position and elevation since just before 1864. This is also significant because these data “lock” the downstream gradient of this watercourse to its current elevation for at least the last 150 years.

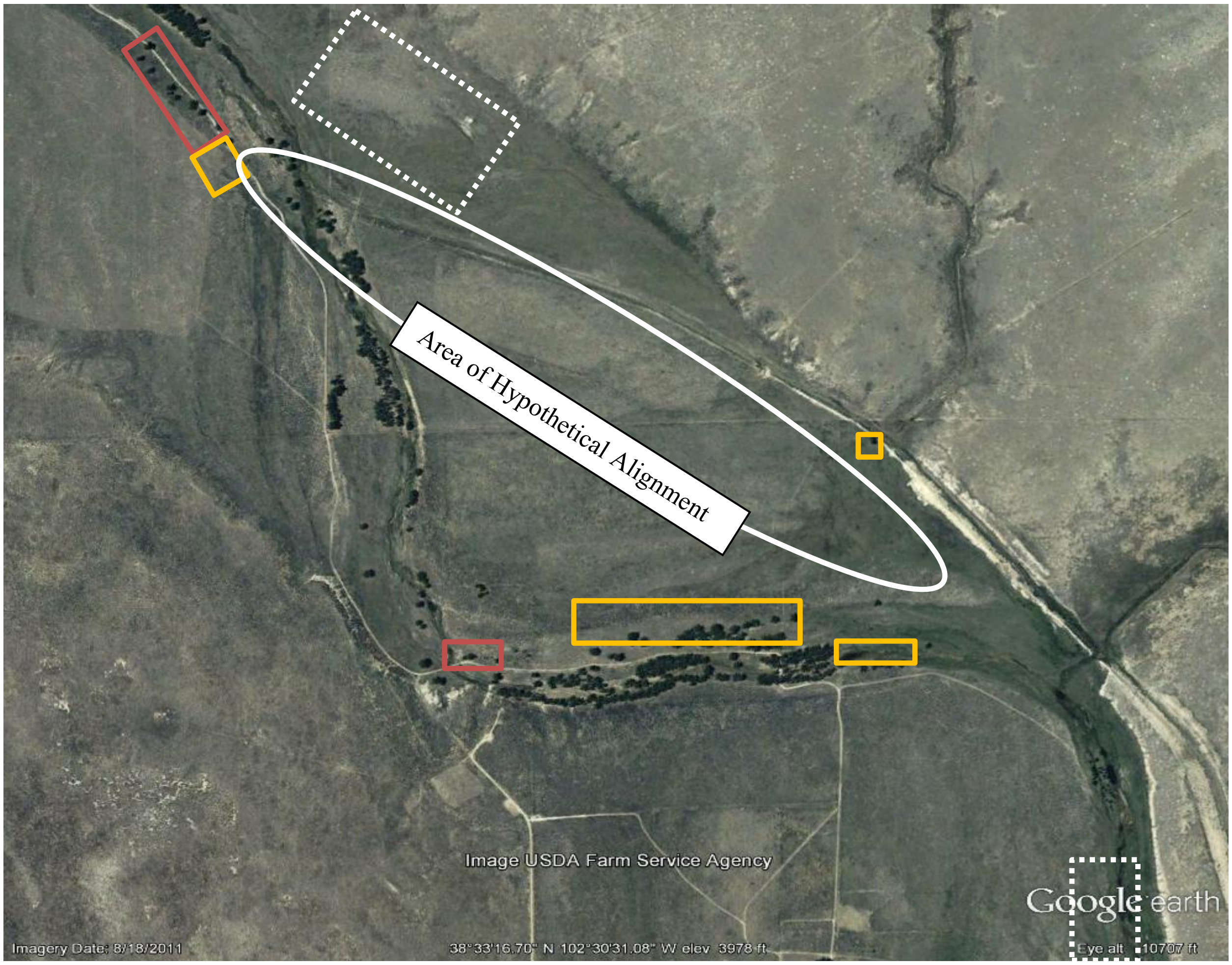


**Figure 11** – Google Earth image of the reach of Big Sandy Creek that is the subject of this report. The white oval depicts the approximate area where the hypothesized channel would have been. The red and orange rectangles mark the locations of "period" trees (1865-1885) and "century" trees (1908-1925), respectively. The dashed white rectangles mark the approximate locations of the two radiocarbon dates (top-center) and the lead-210 date (bottom-right).

## Re-Cap

Since the question was raised that the active channel of Big Sandy Creek may have been in another alignment in 1864, the time of the Massacre, we have undertaken literature review, reconnaissance level field assessment, detailed soil analyses, and geospatial analyses of lidar data. Throughout all of this data review and gathering, we have been unable to find any physical or biological evidence suggesting that Big Sandy Creek was in the area of the proposed alignment at or near the time of the Massacre. Furthermore, all indications are that the active channel of BSC has been within about 200 to 500 feet of its current alignment for the past 150 years or so.

**References Cited:**

Coffin, D.L. and C. A. Horr, 1967. Geology and Ground-Water Resources of the Big Sandy Creek Valley Lincoln, Cheyenne, and Kiowa Counties, Colorado. USGS-Water Supply Paper 1843.

CWCB 1998. Colorado's 1997 flood season in review. The Colorado Water Conservation Board, produced by Riverside Technologies.

Holmes, A.M. and M. Mcfaul, 1999. Geoarcheological Assessment of the Sand Creek Massacre Site, Kiowa County, Colorado. Final Report – LaRamie Soils Service, P.O. Box 255, Laramie Wy 82073.

Lukas, J and C. Woodhouse, 2006. Riparian Forest Age Structure and Past Hydroclimatic Variability, Sand Creek Massacre National Historic Site. Final Report – Institute of Arctic and Alpine Research (INSTAAR), University of Colorado – Boulder.

Ries, K.G., III, and Crouse, M.Y., 2002. The National Streamflow Program. A computer program for estimating magnitude and frequency of floods for ungagged sites, 2002. U.S. Geological Survey Water Resources Investigations Report 02-4168.